Subsurface Lithofacies Analysis of Barakar Coal Measures of Talcher Colliery, Talcher Coalfield (Orissa).

BY

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I certify that work presented in this dissertation has been carried out and completed by Mr. Arun Kumar Singh Raghuvanshi under my supervision at the Department of Geology, Aligarh Muslim University.

This work is an original contributions to the knowledge of subsurface facies analysis of the Barakar stratum, Talcher colliery, Talcher coalfield. The research work presented here has not been published anywhere in part or in full.

I recommend that Mr. Arun Kumar Singh Raghuvanshi be allowed to submit the dissertation for the award of the degree of MASTER OF PHILOSOPHY IN GEOLOGY of the Aligarh Muslim University.

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Supervisor

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INTRODUCTION

GENERAL REMARKS

Early studies of Gondwana rocks in Talcher coalfield were connected with geology and coal exploration (Kittoe, 1838; Blanford et al., 1856; Fermor, 1918; Naraynamurthy and Subramanian, 1956). The Indian Bureau of Mines carried out further exploration of coal during 1957-1961. However, little attention has been paid so far on the sedimentology of Gondwana rocks in this coalfield.

In recent years, stratigraphers and sedimentologists engaged in the study of Gondwana rocks are trying to focus attention on subsurface analysis of lithologies with a view to bring out areal variation of lithic composition, facies pattern basin geometry and depositional environment. Such studies indeed are vital for basin analysis and for reconstructing a sedimentary model objectively. A brief study on these lines has been undertaken recently on Kothagudem coalfield of Andhra Pradesh (Vijayam and Deshpande, 1979). Likewise, several projects on subsurface analysis of coal measures are in progress or completed in the Department of Geology, A.M.U., Aligarh including that on Moher block of Singrauli coalfield (Casshyap, 1979; Aslam, 1980), Mahuda basin (Casshyap, 1981), Monidih block of Jharia coalfield (Kumar, 1981), Manikpur block of Korba coalfield (Casshyap, 1982). A sedimentological study of this nature has not been attempted so far on the Barakar of Talcher coalfield and the results are critically needed from this area for a regional synthesis of Son-Mahanadi Gondwana basin in light of the work in progress at this Department.

CHOICE OF AREA

The Talcher coalfield situated in the district of Dhankanal of Orissa was selected for this investigation because it represents the southernmost outlier of the Son-Mahanadi Gondwana basin belt, and the possible potential of coal and subsurface geology and lithofacies distribution have not been adequately worked out so far in this remote basin. This coalfield has been re-examined lately by the officers of Geological Survey of India, and Central Mine Planning and Design Institute Limited (C.M.P.D.I.L.), a subsidiary of the Coal India Limited.

LOCATION AND PHYSIOGRAPHY

The study area is located in and around Talcher colliery which forms the eastern part of Talcher coalfield (Fig. 1) covering an area about 10 sq km and is situated in the Survey of India Toposheet No. 73H/1 between North Latitudes $20^{\circ}55'$ - $21^{\circ}00'$ and East Longitudes $85^{\circ}10$ - $85^{\circ}15'$. The Cuttack-Sambal Trunk road passes near the southern boundary of coalfield from which some branch roads pass through the coalfield. The nearest railway station is Talcher on the Puri-Talcher branch line of the Southeastern Railway.

The Talcher coalfield is predominently covered by soil and is gently undulating. The surface elevation varies from

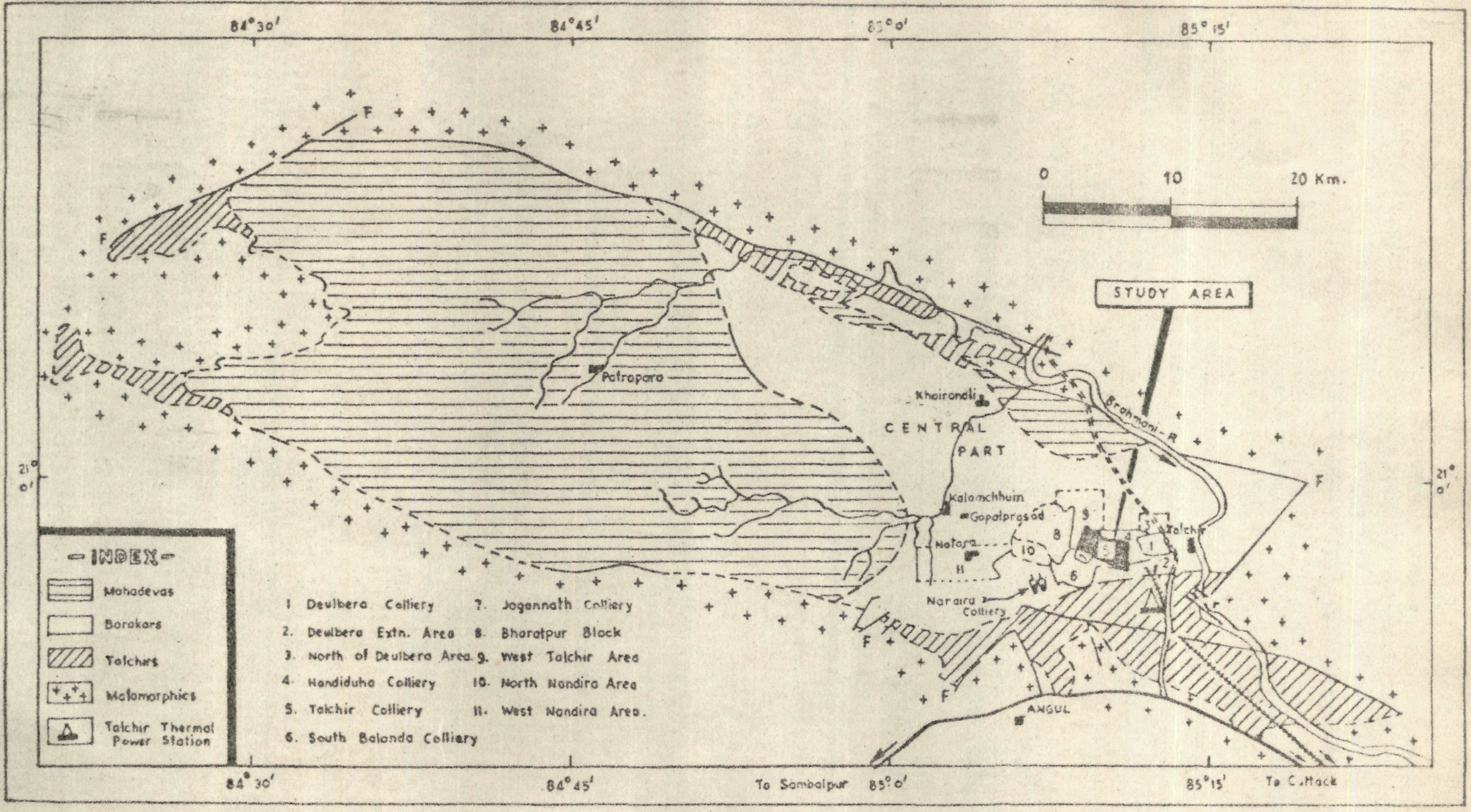

Fig. 1 : Map showing location and Gondwana geology of the Talcher coalfield.

103 m to 150 m or more above the mean sea level. The rock exposures are limited along river cutting, nala cutting, at flat topped ridges and knolls. The Brahmani river passes across the area flowing more or less north to south at Talcher town (Fig. 1). There are several tributaries of this Brahmani river, namely Nandira jhor, Singhdha jhor, Murara jhor, Bhalutungri nala, Bangru jhor etc. which are generally flowing west to east.

OBJECT

The investigation aims at : (i) analysing quantitatively subsurface lithofacies to determine the extent of areal variation in thickness and areal despersal of dominant lithofacies; (ii) analysing cyclicity of the given Barakar sequence and comparing the cyclical sequence with that deduced in other coalfields of Son-Mahanadi and Damodar-Valley basins; (iii) interpreting basin framework and environment of deposition of Barakar lithiofill in the given area.

ACKNOWLEDGEMENTS

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The author is thankful to the staff of Talcher colliery for providing lithologs and necessary facilities. The author gratefully acknowledges a research grant from the Council of Scientific and Industrial Research, New Delhi in the form of an award of a Junior Research Fellowship.

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CHAPTER - I

STRATIGRAPHY AND SEDIMENTARY CHARACTERS OF BARAKAR STRATA

GONDWANA STRATIGRAPHY

The Talcher coalfield covering an area of about 1800 sq km is a flat type basin of Gondwana rocks bounded on all side by unclassified Archean granite and gneiss. Total thickness of Gondwana rocks including Lower (Permian) and Upper (Triassic) Gondwana is of the order of about 1550 meter.

Although Kittoe (1838) and the geologists of the Coal Committee (1845) first reported occurrence of coal in Talchir coalfield, a detailed geological map of the coalfield was first prepared by W.T. Blanford, et al. (1856) during their search for coal. L.L. Fermor examined the coal outcrops near Gopalprasad in 1918 (Fig. 1) and recommended drilling in the area to find out the possibility of more coal. Following his recommendations and those of Narayanamurthy and Subramanian (1956), the Indian Bureau of Mines resurveyed the area for detailed exploration by drilling in several areas during 1957-1961.

The study area in and around Talchir colliery is situated on the Barakar Formation of Lower Gondwana. The Lower Gondwana Formations lie unconformably on or are faulted against the basement of Archean metamorphics through most part along the southern and north boundary. Regional strike of the strata is largely in east-west direction and dip towards north, so that the Lower Gondwana formations (Talchir, Karharbari, Barakar and Raniganj) outcrop successively from east-southeast towards west-northwest, overlain by the Upper Gondwana rocks (Panchet and Mahadeva) in the western and northwestern parts. A number of intra-basinal faults locally displace the strata.

The stratigraphy of the Talcher coalfield modified after the Geological Survey of India (Subramaniam, 1971) is summarised below in ascending order :

Subdivision	Age	Group	Formation
Upper Gondwana	Middle Triassic	Mahadeva ($\sim$400 m)	
	Lower Triassic	Panchet (7 210 m)	
Lower Gondwana	Permian	Damuda (800 m)	Raniganj (150-180 m)
			Barakar (340-390 m)
			Karharbari (230-270 m)
	Permo - Carboniferous	Talchir (150 m)	

Archean

The coal bearing Karharbari and Barakar dominate in the eastern part of the coalfield, covering over 500 sq km and presumably continue below the Panchet and Mahadevas towards west and northwest. Coal is being explored in the Barakar strata by the Central Coal Limited (C.C.L.) in the eastern part where eleven collieries are presently situated including Talchir colliery, Dera colliery, South Balanda colliery, etc., as shown in Fig. 1.

SEDIMENTARY CHARACERS OF LITHOFACIES

The Barakar strata are dominantly arenaceous, consist of sandstone from base to top, occasionally interbedded with thin bands of shale and coal which are by and large more common in the upper part. The various lithofacies as recognised in the field and their sedimentary characters as recorded in outcrops are summarised below :

Sandstone Facies

Sandstone varies from gritty, coarse and medium to fine grained. Gritty and coarse grained sandstone occurs dominantly in the lower part. It is dirty white to grey in colour; individual bodies vary from about 3 - 35 m in thickness and laterally persist an outcrop for tens of meters. Large scale cross-bedding is profusely developed and occurs in grouped and solitary sets. This subfacies commonly is overlain by coarse to medium grained sandstone bodies which are thicker than 10 m. Their bedding traces are faint to well developed and straight to undulatory, and large scale tabular and trough cross-bedding occur more often than small scale cross-bedding. Fine grained sandstone often occurs as thin bodies interbedded with shale.

Interbedded Facies

Sandstone facies is commonly succeeded by interbedded facies in which fine grained sandstone occurs as thinner bodies(1 - 3 m), locally showing small scale cross-bedding, and parallel laminations more than ripple marks. Thin beds of shale show wavy contacts with fine sandstone.

Shale and Carbonaceous Shale Facies

Shale as a separate facies is not much wide spread and generally shows gradational contact with interbedded facies. Its thickness varies from 1 - 3 m. Locally it changes to carbonaceous shale through gradational contact with underlying shale and sharp contact with overlying coal.

Coal Facies

Coal occurs as thin and laterally persistent seams. Individual coal seams in outcrops vary from 15 - 90 cm in thickness or more, with intercalations of carbonaceous shale and sandstone although some coal seams recorded in borehole logs are more than 16 m in thickness.

The Talcher coals are usually of high moisture (6.2%), medium to high volatile (32%), lower in rank, non-coking and dull in appearance (Subramanian, 1971).

CHAPTER - II

SUBSURFACE STUDY OF LITHOFACIES

FACIES DEFINITION AND CONCEPT

A systematic mapping of facies in subsurface can provide a three dimensional picture of a stratigraphic unit and form a basin analysis, sedimentologic framework, and for palaeogeographic and paleotectonic interpretation (Forgotson, 1960; Krumbein, 1952; Krumbein and Sloss, 1963). The term facies should be considered to "comprise any areally seggregated part of a designated rock division in which physical / organic characters differ significantly from those of another part or parts" (Krumbein and Sloss, 1963, p.). Reading (1978, p. 4) defines sedimentary facies in many different sense : (1) in the strictly observational sense of a rock product, e.g. sandstone facies, (2) in a genetic sense for the products of a process by which a rock is thought to have formed, e.g. "turbidity facies" for the products of turbidity current, (3) in an environmental sense for the environment in which a rock or suite of mixed rocks is thought to have formed, e.g. "fluvial facies" or "shallow marine facies" and (4) as a tectofacies, e.g. "post orogenic" or "molasse facies".

As used in this study the term "lithofacies" represents various aspects of stratigraphic units in terms of gross lithologic character at any single geographic location either from measured section or from borehole logs (Krumbein and Sloss, 1963).

The lithological aspects of a stratigraphic unit may be expressed in terms of total thickness of different units, say sandstone, shale and coal etc. and also their individual percentage in a stratigraphic unit. The lithologic attributes and their variation across the basin can be graphically represented with the help of relevant facies maps.

Facies maps either individually or in combination provide information regarding the regional facies trends, possible direction of clastic transport and location of source area, outline of major tectonic elements, nature of zero line and influence of structure on deposition (Krumbein, 1952; Krumbein and Sloss, 1963; Prayor, 1960; Forgotson, 1960; Krumbein, Sloss and Dapples, 1963; Fisher et al., 1969; Casshyap, 1981).

TYPES OF FACIES MAPS

A variety of facies maps are known to be used either individually or in combination according to the object in view. Forgotson (1960) classified the facies maps into following categories :

1. Maps which illustrate geometrical configuration of three dimensional body. e.g. Isopach maps.
2. Maps which indicate composition of a stratigraphic unit. These maps can be divided into two classes according to the number of variables considered :

A. Univariate - (i) Isolith maps

(ii) Percentage maps

B. Multivariate - Ratio maps e.g. Combined ratio maps, entropy function maps and distance distributions maps describe the relationship among three variables.

3. Maps which describe either the degree of differentiation of a stratigraphic section into described units of different lithological types, or the vertical distribution of one lithological type with in a stratigraphic unit. e.g., vertical variability maps.

4. Mapsbbased on either a statistical analysis or other kind of mathematical treatment of contour map datas, e.g. variance maps, regional and local component maps, rate of change maps, and high order derivative maps.

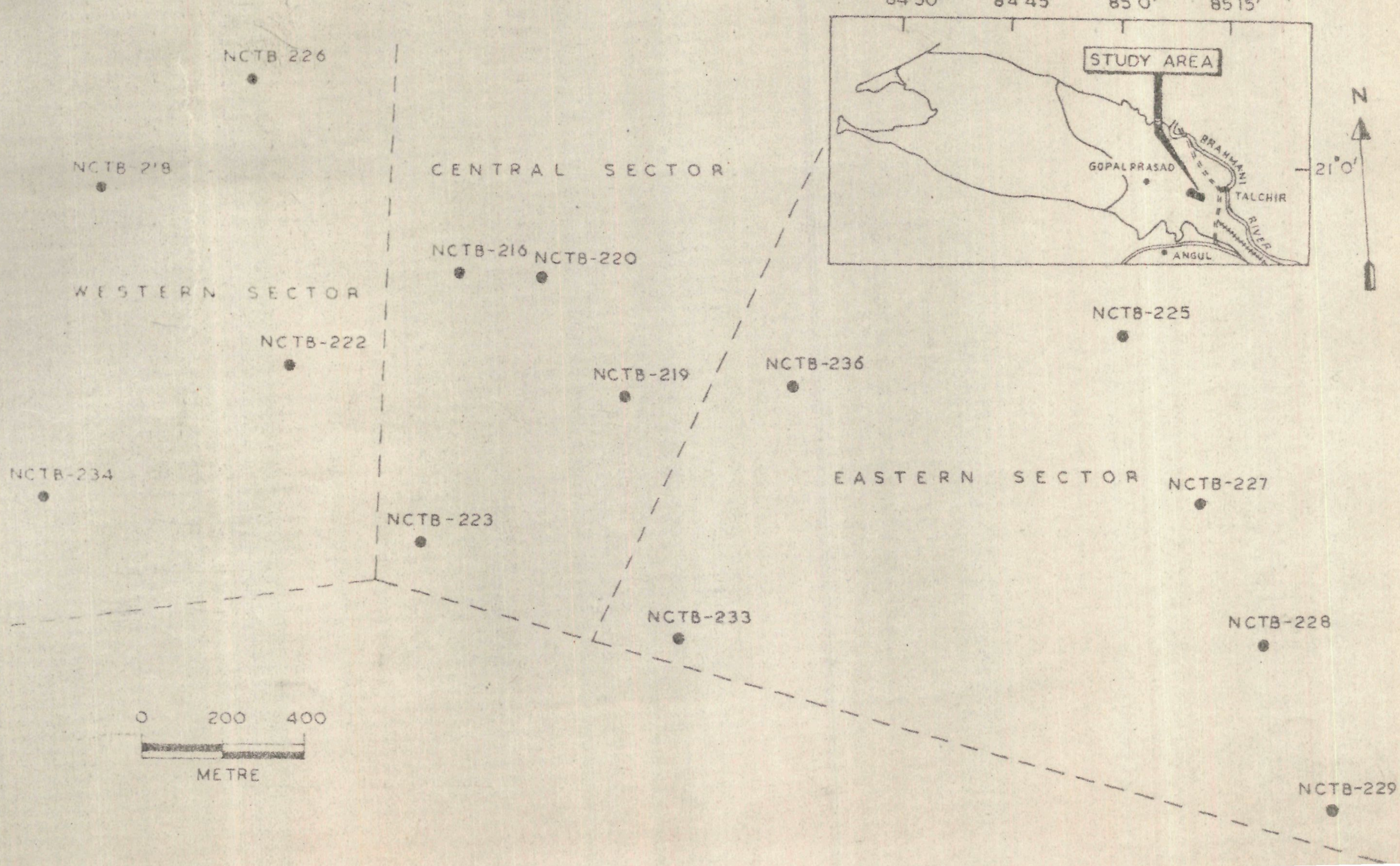
For the purpose of present study, facies maps belonging to classes 1 and 2 were prepared and used. Further, a fence or panel diagram was prepared to work out subsurface geometry of interbedded lithofacies including coal. In addition, subsurface facies maps were prepared for the stratum bounded by two arbitrary key horizons made up of coal seams, the upper one called the "Marker horizon" and the lower one the "Bottom seam", the names proposed by the Geological Survey of India and C.M.P.D.I.L. This study of a specific Barakar stratum is based on 14 borehole logs from different localities as shown in Fig. 2. A sample of borehole log showing vertical sequence of lithofacies and the two marker horizons is reporduced in Fig.3.The subsurface study of facies aims at investigating :

i. Subsurface geometry of sandstone and coal facies by drawing panel diagram for the given stratum.

ii. Areal variation of stratal thickness, by drawing isopach maps.

iii. Areal variation of thikness and relative amount of total sandstone, total shale, total coal, including certain specific bodies of sandstone and coal.

Fig. 2 : Map showing location of borehole logs in Talcher colliery.



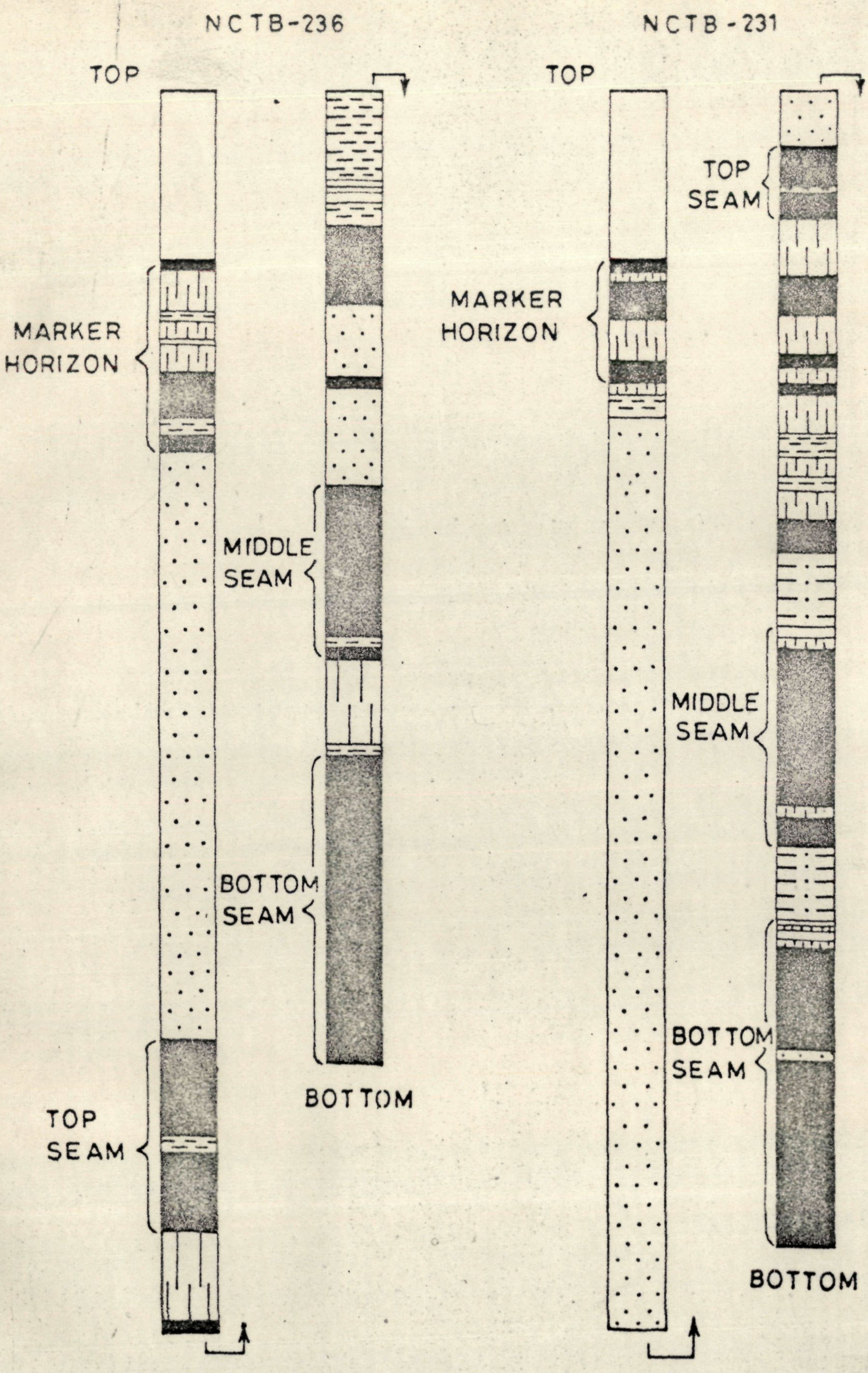


Fig. 3 : Graphic section of Barakar strata showing stratigraphic position of dominant coal seams, reporduced from borehole logs.

Geometry and Distribution of Lithofacies

The panel diagram in Fig. 4 displays three dimensional distribution of lithofacies in the specific Barakar stratum as stated above. Three interbedded facies which constitute the given stratum are sandstone, coal and shale. By averaging their amount (by volume) in total borehole logs, the strata include some 45.5% sandstone, 43.5% coal, and 7.5% shale (Table 1).

The lateral correlation of individual sandstone bodies and fine clastic (shale) facies in different borehole logs was made possible on the basis of recorded nomenclature of coal seams as given by C.M.P.D.I. officers and shown in panel diagram (Fig. 4) namely :

i. Marker horizon
ii. Top coal seam
iii. Middle coal seam
iv. Bottom coal seam

The sandstone bodies occur repeatedly in the vertical column interbedded with fine clastics, and are found both as continuous and discontinuous bodies varying in thickness from 1--18 m. There is one thick (12 - 18 m) continuous sandstone body between the "Top coal seam" and the uppermost coal seam called the "Marker Horizon". This prominent sandstone body, referred to as Middle Sandstone in this study, decreases in thickness from east-southeast to west-northwest. It occurs as a sheet like body (Potter, 1962) and includes thin lenses of fine clastic in the lower and upper parts (Fig. 4). Discontinuous bodies of sandstone are lensoid and apparently channel shaped (Dupuy et al., 1963; Pettijohn, et al., 1972), 1 - 5 m in

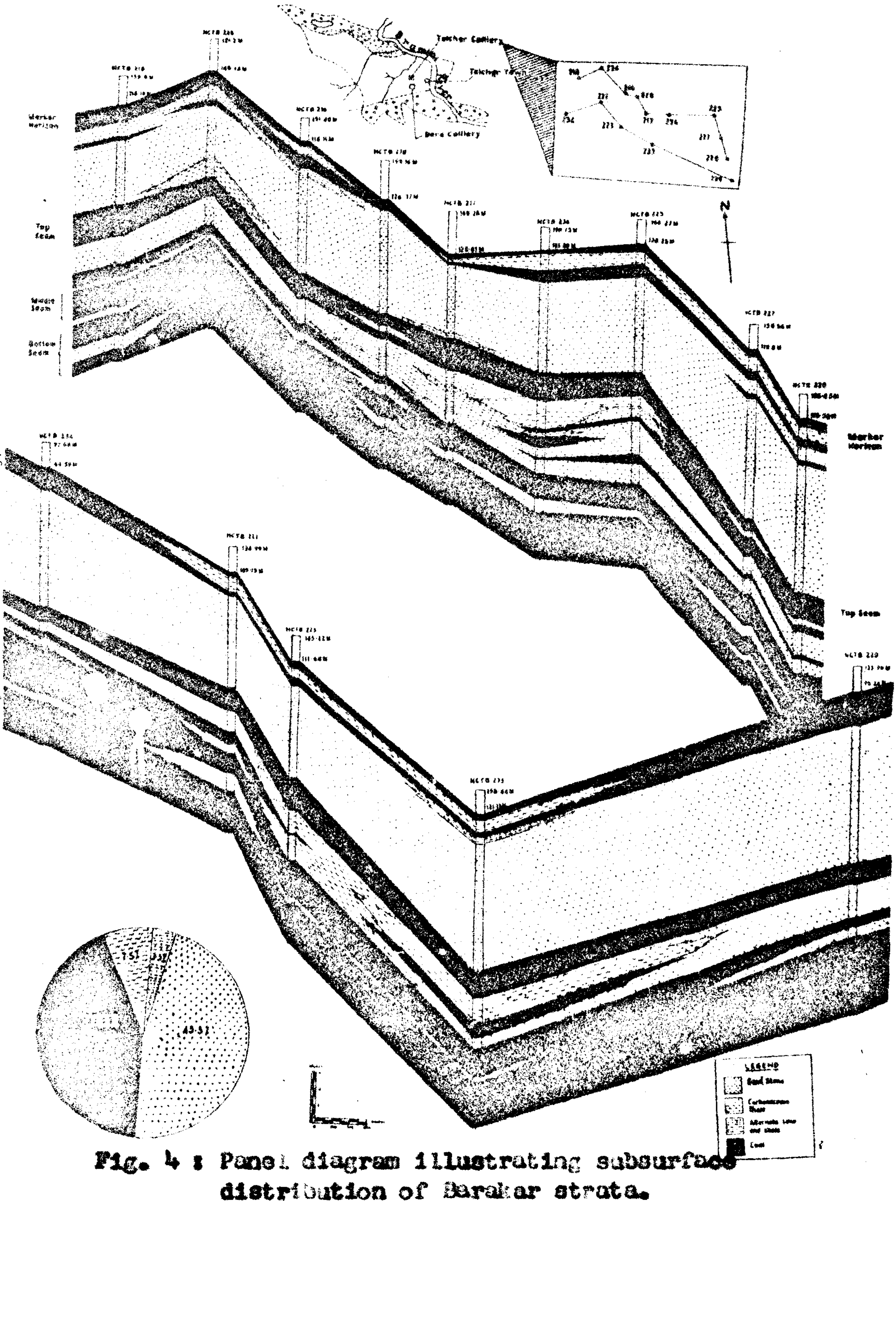


Fig. 4 : Panel diagram illustrating subsurface distribution of Barakar strata.

Table - 1 : Raw Data for Lithofacies Maps. and total
Percentage of different lithologic type.

ole No.	Total Thickness of bore-hole (meter)	Total sandstone thickness (meter)	Total sandstone percentage	Total shale-thickness (meter)	Total shale percentage	Total coal thickness (meter)	Total coal percentage	Sand-shale ratio
B. 216	32.38	13.9[illegible]	43.14	3.61	11.16	14.80	45.7	4
B. 217	29.76	10.81	36.30	5.92	19.90	13.03	43.78	2
B. 218	29.53	12.61	42.70	2.31	7.83	14.61	49.47	6
B. 220	30.38	13.75	45.85	4.47	14.91	11.77	39.24	3
B. 222	30.38	15.30	50.36	2.19	7.22	12.89	42.42	7
B. 223	31.36	11.88	37.88	5.81	18.85	13.57	43.27	2
B. 225	37.39	18.03	48.22	5.65	15.12	13.71	36.66	3
B. 226	32.52	10.11	31.08	5.91	18.22	16.[illegible]	50.70	2
B. 227	38.08	20.86	54.77	2.38	66.26	14.84	38.97	9
B. 228	38.55	19.59	50.88	3.51	9.05	15.45	40.07	6
B. 229	38.61	20.56	53.20	1.62	4.25	16.43	42.55	13
B. 233	36.86	16.59	45.00	5.26	14.28	15.01	40.72	3
B. 234	33.05	15.04	45.50	2.06	6.24	15.95	48.26	7
Total Percentage			45.50%		11.00%		43.50%	

thickness and 500 m to 2 km in width and are enclosed in or shown intertonguing relationship with fine clastics or coal seams.

The coal seams likewise occur as continuous and discontinuous bodies, ranging in thickness from 1 to 8 m. The four prominent coal seams listed above are more or less continuous locally enclosing lenses of fine clastics and sandstone which tend to split the seams, a common phenomenon of the Barakar coal seams of Son-Mahanadi basin. Significantly each one of these coal seams may rest or be overlain by more than one lithologic type, which may be sandstone in places, shale or carbonaceous shale, or be interbedded facies. This relationship of coal seams with varying lithofacies at base or top is of genetic importance and calls for a proper explanation to be offered later. The coal seams are by and large thicker in the lower part and progressively thinner in the upper part.

Discontinuous lenses of coal seam, 1 - 3 m thick, occur betwen shale above and sandstone below or are enclosed in shale or sandstone, as shown in panel diagram (Fig. 4).

The fences of the panel diagram do not close in the western or eastern direction due to lack of proper borehole logs. Apparently, the lithofacies including coal seams should extend laterally in either direction beyond the limit of Talcher colliery.

Facies Analysis

For analysing various aspects of basin-fill and constituent lithofacies of the given Barakar stratum, the corresponding facies maps as defined earlier were prepared, based on the available borehole logs.

Areal Variation of Total Thickness :

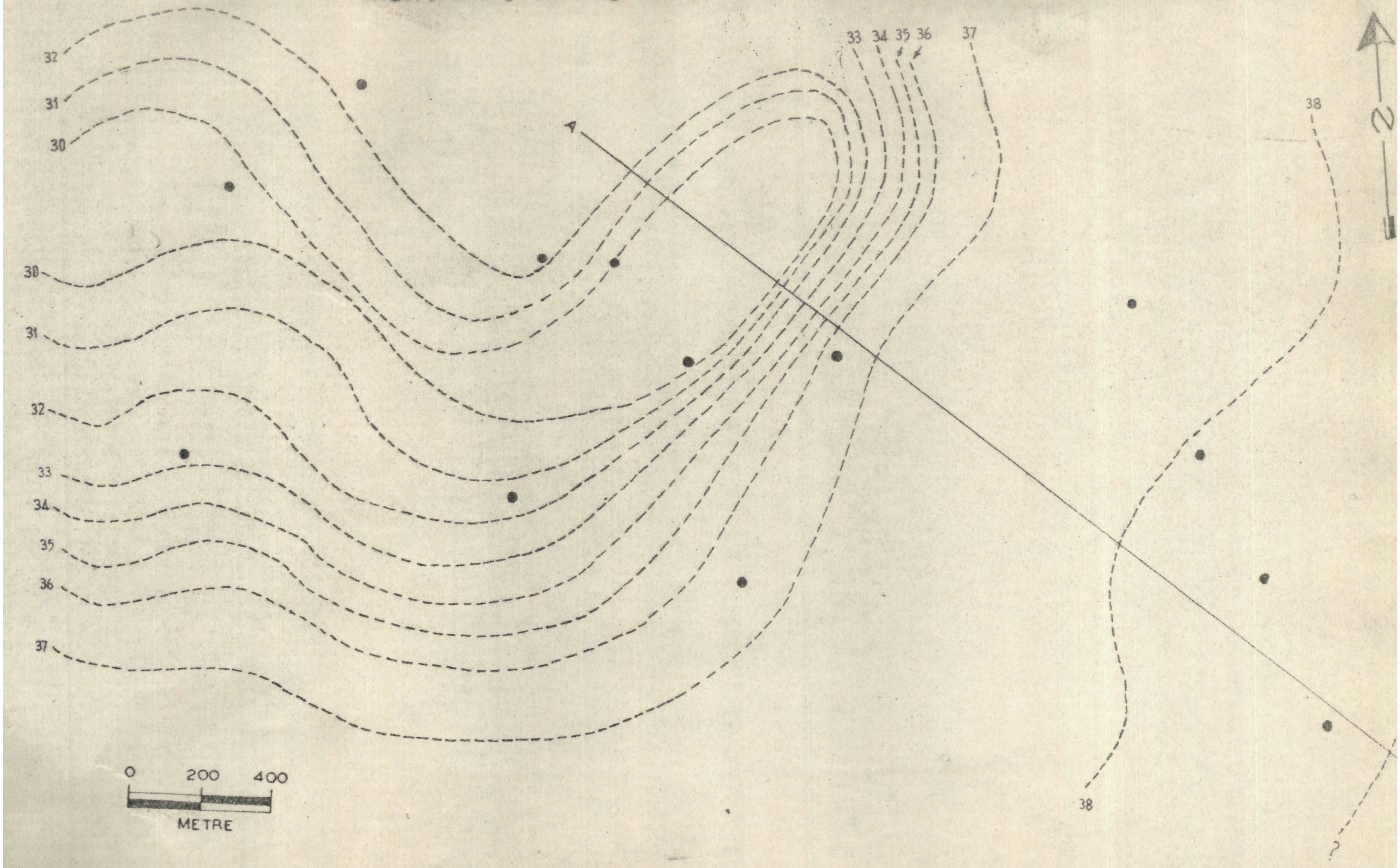
This attribute was investigated by structuring an isopach map for the stratum bounded by the two key horizons referred to above. Inasmuch as an isopach map represents a palaeostructure map of a specific stratum, the data used for this study disregard thickness of the soil cover and that of the strata occurring above and below the two key horizons, respectively. The isopach map in Fig. 5 reveals a more or less elongate basin trending northeast - southwest, with maximum thickness of 39 meter in the southeast and northwest, decreasing to less than 30 meter in central part. Spacing of formlines may suggest that the subsiding basin which had a steeper profile on either side of the upwarped central part gradually became gentler towards outer peripheral sides in southeast and northwest as is evident from the section A - B (Fig. 6). The closure of formlines in the northeastern part by extrapolation because of lack of borehole logs is apparent and needs varification.

Sandstone Isolith Maps :

These maps were prepared to examine thickness variation for total sandstone and separately for the prominent sandstone body, called here Middle Sandstone.

When total thickness of sandstone in a given stratigraphic unit is recorded at each control point and lines of equal sandstone thickness are drawn through the area, the map is referred to as a sandstone thickness or sandstone isolith map as shown in Fig. 7. The isolith map brings out greater development of sand-

Fig. 5 : Map showing variation in total thickness of Barakar strata.



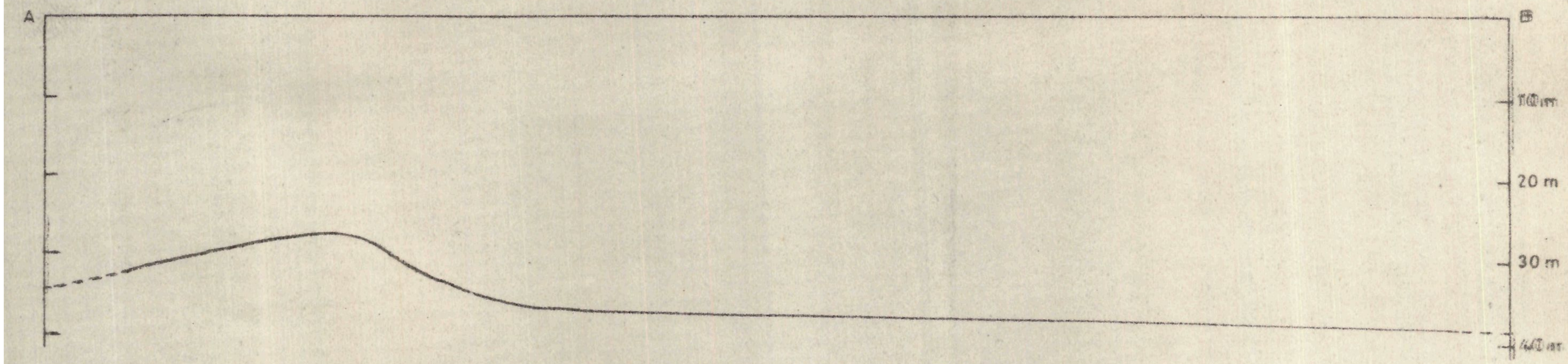
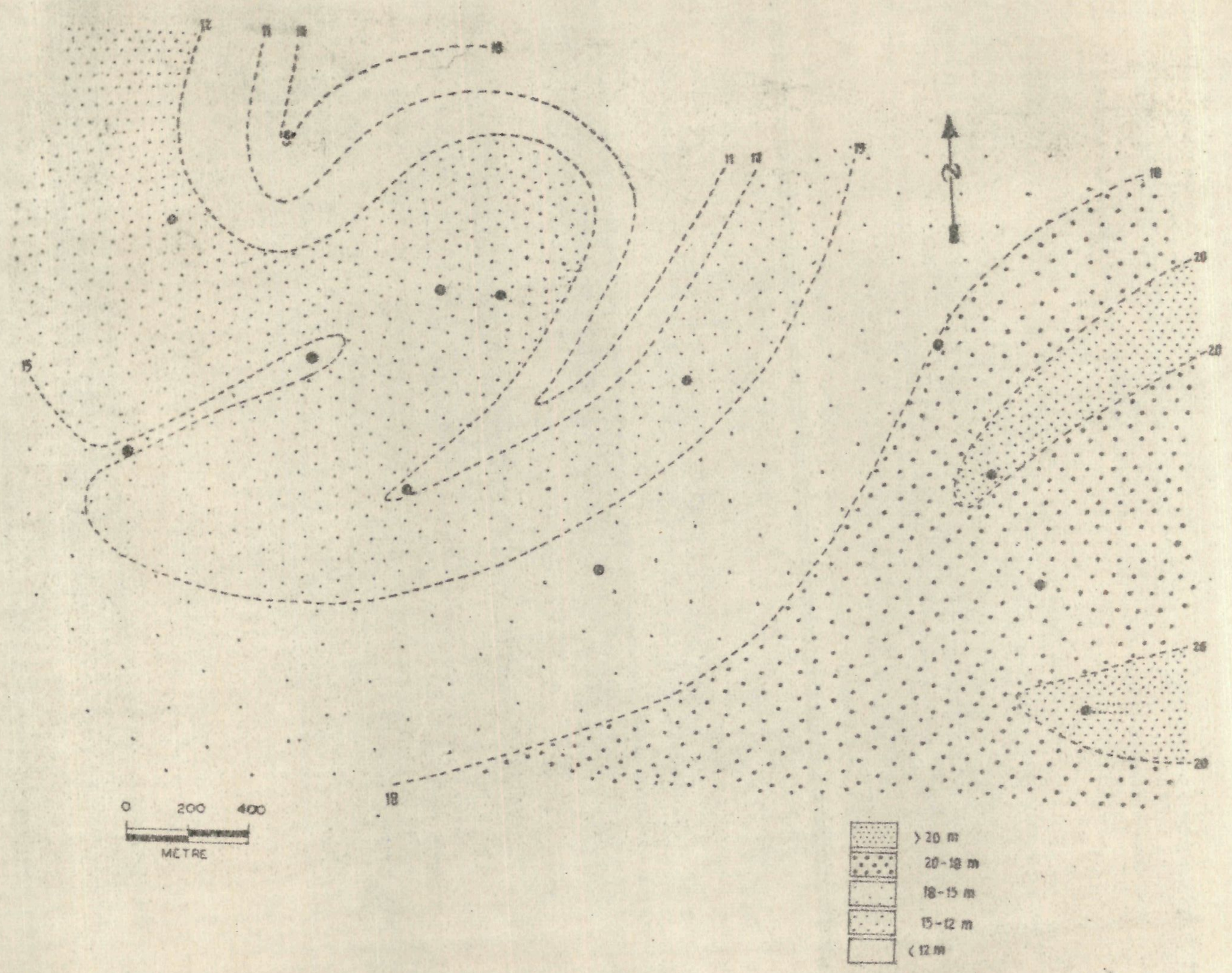


Fig. 6 : Section line of isopach map along A-B (Fig. 5) showing extent of subsidence across the area.

Fig. 7 : Sandstone isolith map showing variation in total thickness of sandstone across the area.



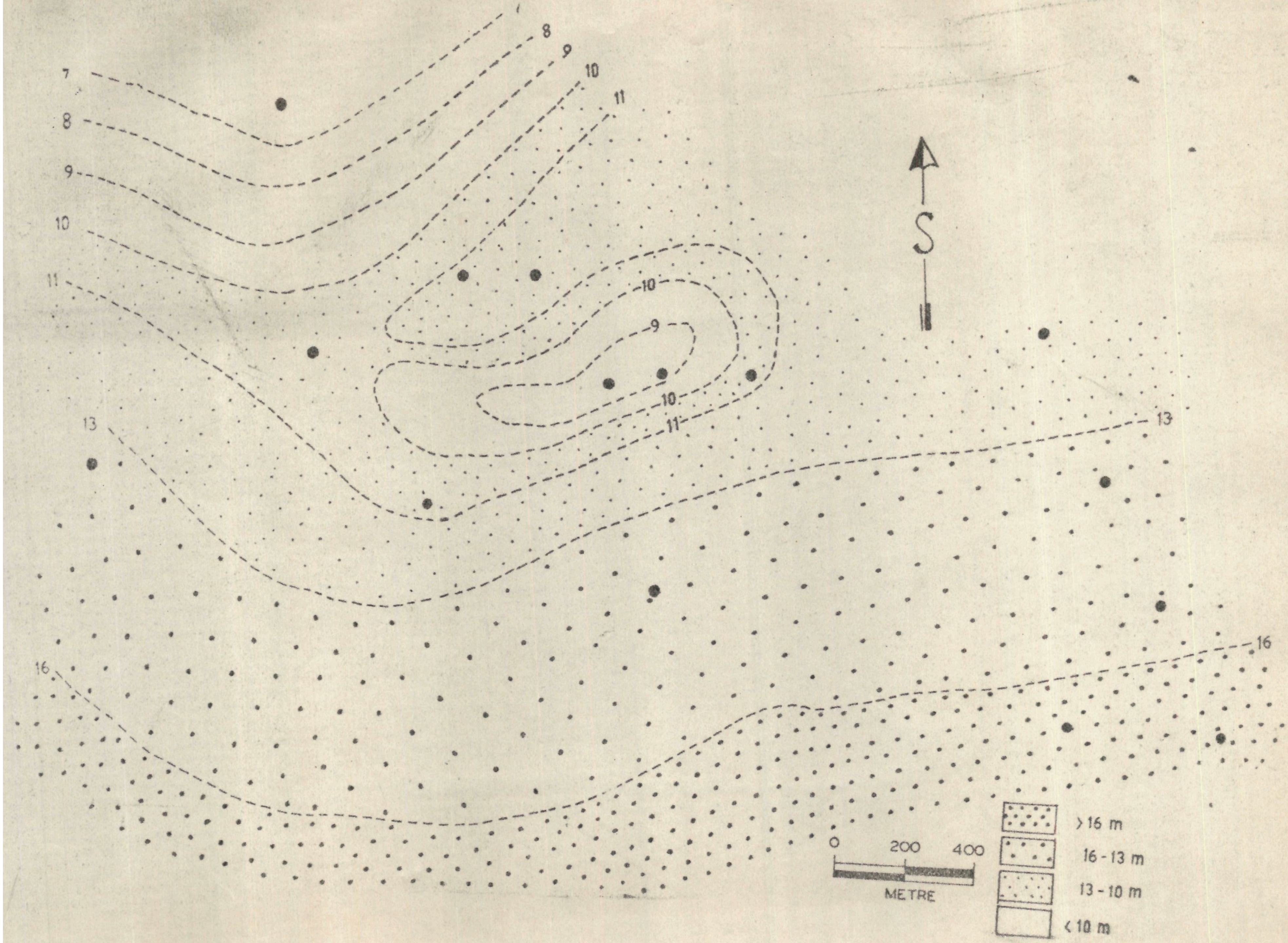
stone (thickness > 12 m) during the course of Barakar sedimentation in the eastern and southeastern part with a tendency to dec decrease (< 10 m) in the north and northcentral parts. The form lines trending northeast-southwest along thelength of the basin swing back and forth from southeast towards northwest, and vise-versa.

The Middle Sandstone shows maximum thickness in southern part, decreasing progressively towards north. This sandstone shows by and large the same pattern of thickness as recorded for total sandstone, i.e. it thickens and thins in same direction as total sandstone. The distribution of thickness and orientation of formlines trending northeast-southwest may suggest that depositional channel for this sandstone had its width oriented east-northeast (ENE) westsouthwest (WSW) as shown in Fig. 8 and length across the width in southeast-northwest direction. Cross-bedding resutls reported from this area suggest a palaeoflow from southeast to northwest (Casshyap, 1973).

Percentage and Ratio Maps :

These maps are drawn to show relative amount of different lithofacies. Percentage maps were drawn separately for sandstone and shale and a sand-shale ratio map was drawn to verify the results of percentage maps. Figure 9 shows that sandstone percentage varies from place to place with maximum (> 54%) occurring in southeastern part and minimum (< 32%) in northwestern part. Form lines of shale percentage map (Fig. 10) show maximum development of fine clastics in central and northern

Fig. 8 : Middle Sandstone isolith map showing variation in thickness of sandstone across the area.



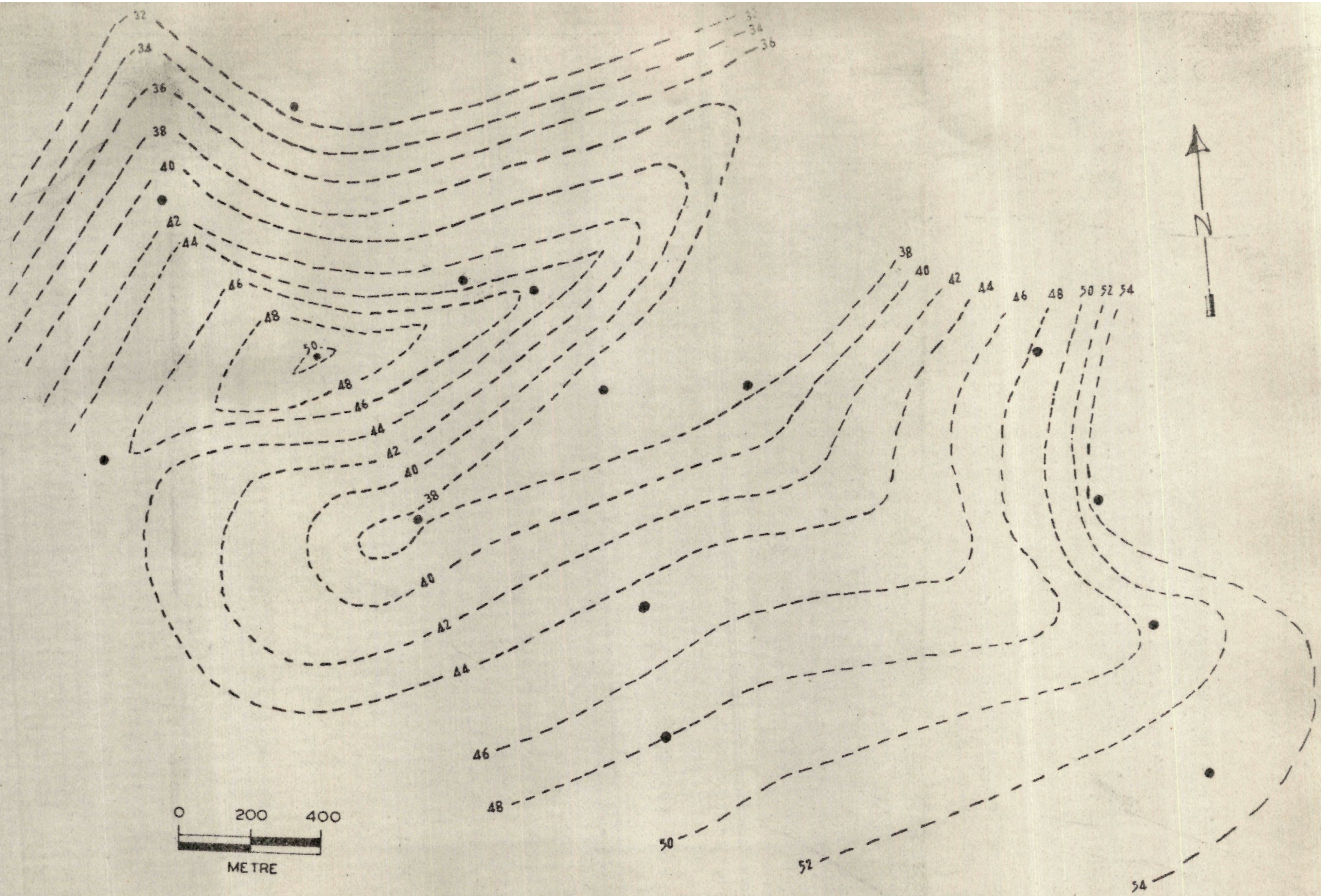
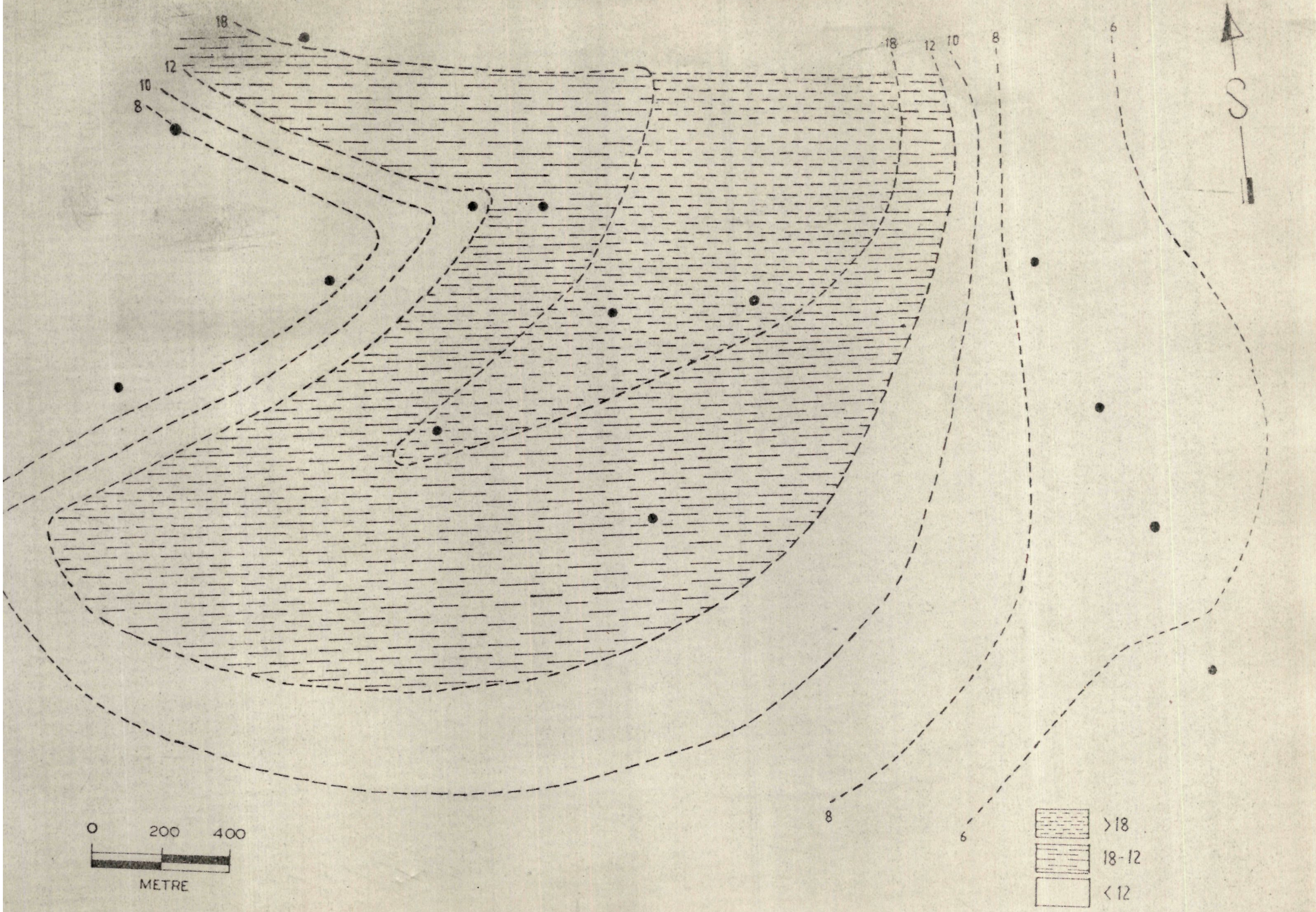


Fig. 9 : Map showing relative percentage of sandstone across the area.

Fig. 10 : Map showing relative percentage of shale across the area.



part (> 18%), gradually decreasing towards south, southeastern and western part down to <6%.

A comparision of percentage maps of sandstone and shale shows that shale developes to a maximum in southeastern part where sandstone is minimum. This is also indicated by sand-shale ratio map (Fig. 11) wherein the ratio value is maximum (> 14) in southeastern part and minimum (< 4) in the north central and northwestern part, though changes in ratio values are gradual as in the case of isolith maps of sandstone and shale.

Coal Isolith Maps :

Areal variation of coal in subsurface was investigated by plotting isolith maps for total coal and for individual coal seams.

The isolith map of total coal (Fig. 12) shows maximum development of coal (>16) in the outer peripheral part of the basin, as against the central part where total coal decreases to less than 12 m.

The form lines tin isolith map of Top Coal Seam (Fig. 13) trending northeast-southwest display zig-zag pattern of thickness. The coal seam is alternatingly thicker (>3 m) and thinner (< 2 m) with former occupying areas in the eastern, central, southeastern and northwestern parts (Fig. 13). This pattern indicates the original shape and configuration of coal swamps and the Barakar flood plain. The shape closely re-sembles that of several modern peat swamps and has a bearing on original configuration of the alluvial plain.

Fig. 11 : Map showing relative distribution of sand-shale ratio across the area.

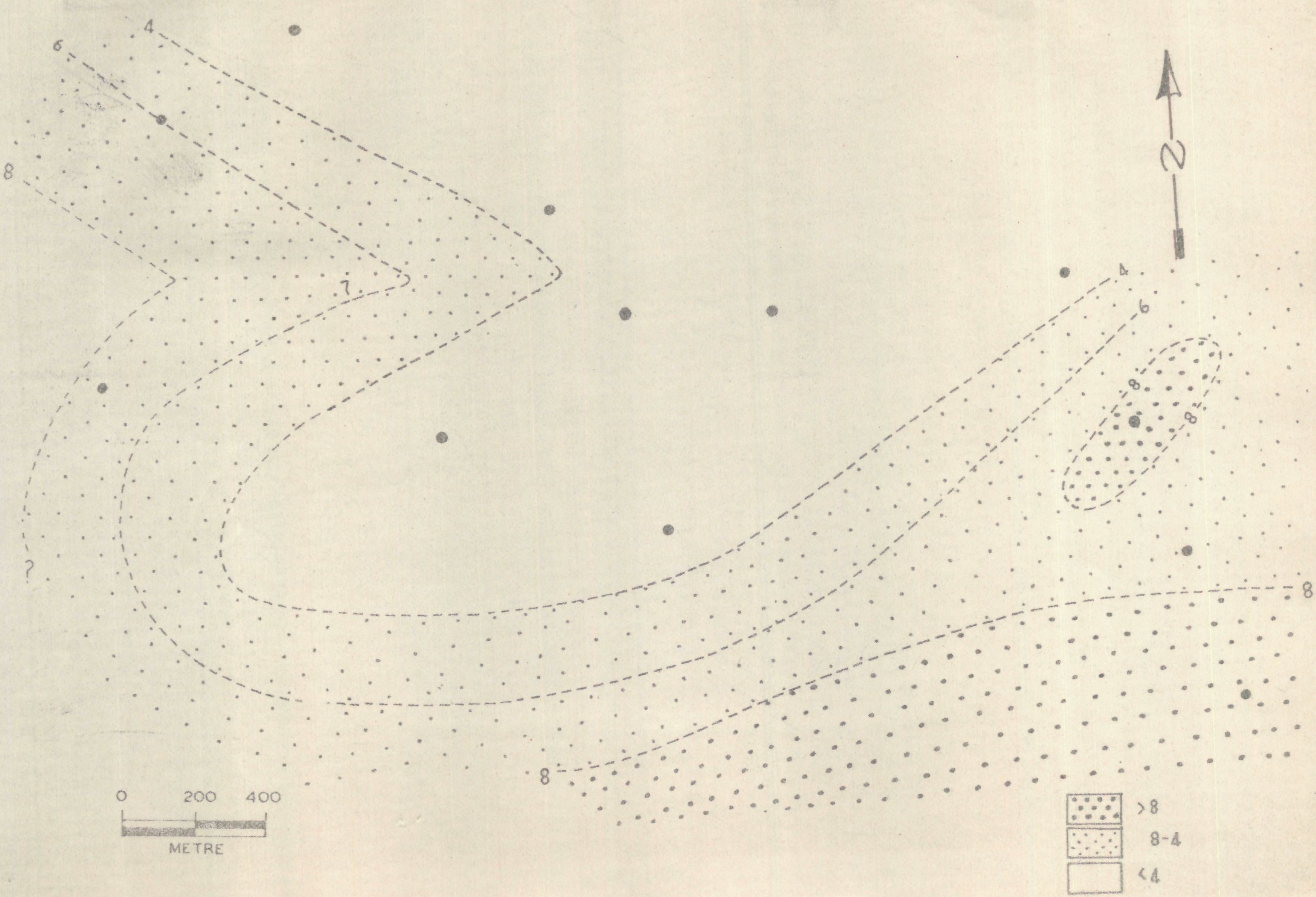
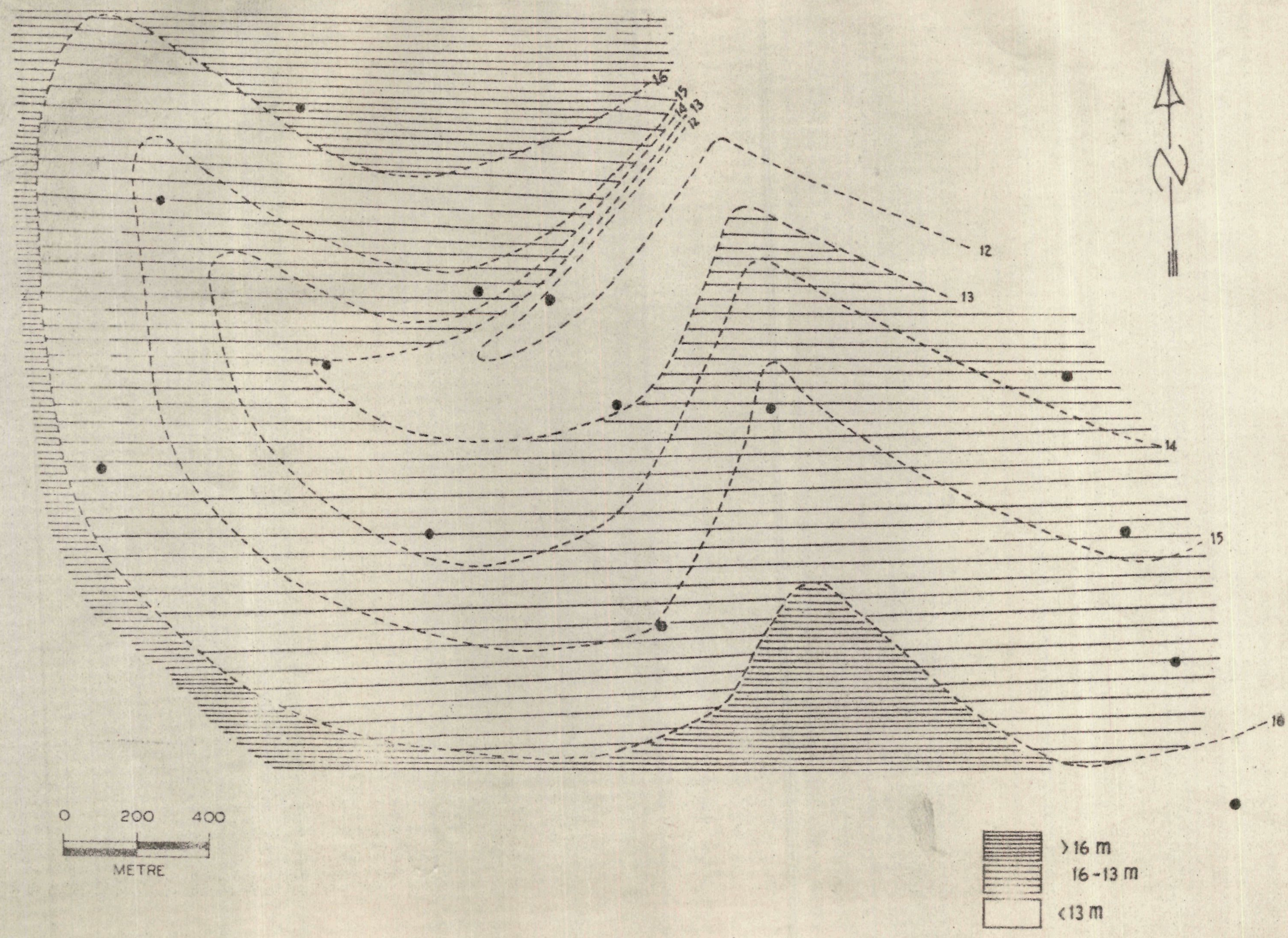


Fig. 12 : Coal isolith maps showing variation in thickness across the area.



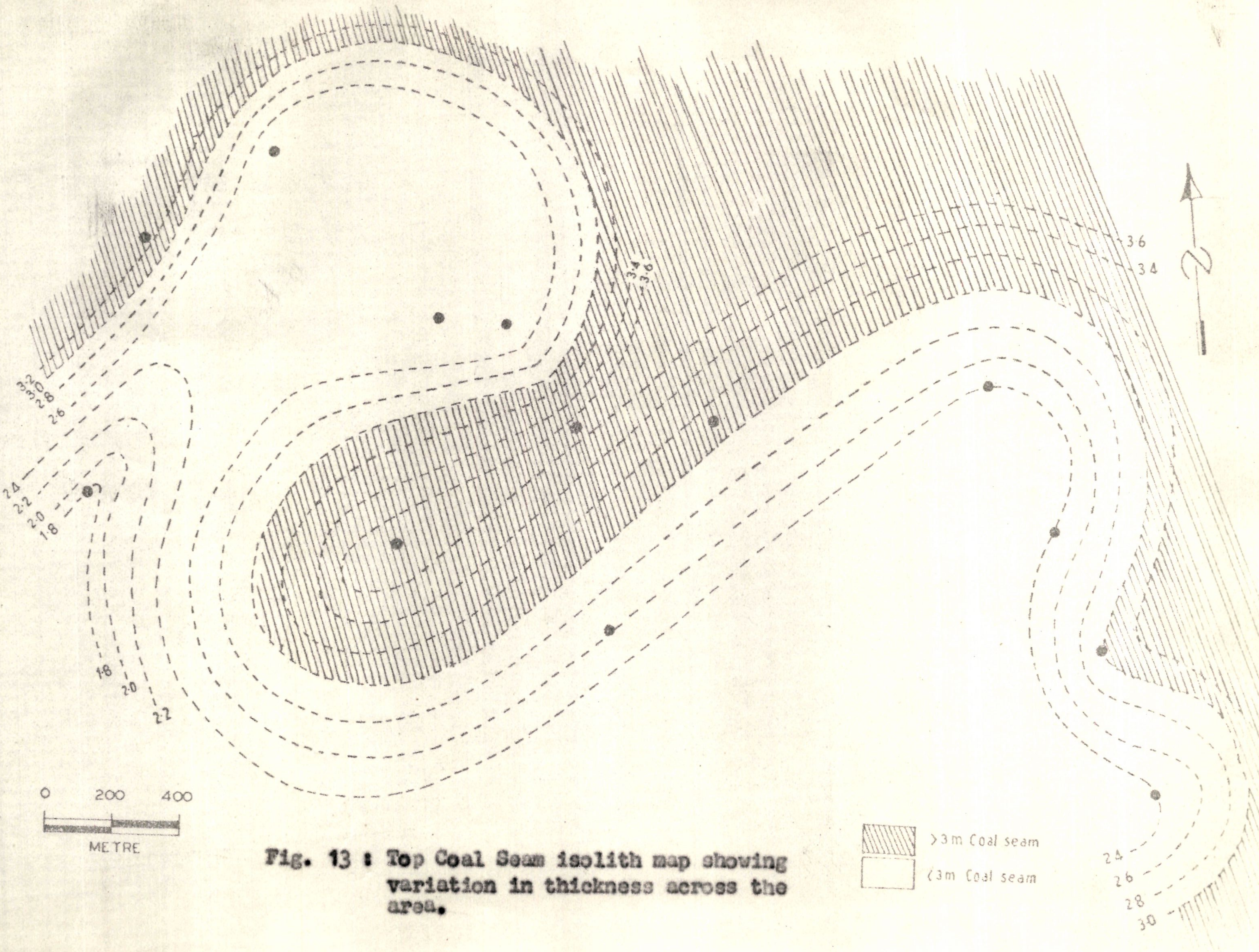


Fig. 13 : Top Coal Seam isolith map showing variation in thickness across the area.

CHAPTER - III

MARKOV CHAIN ANALYSIS

Markov chain statistics has been widely applied in the study of sedimentary sequences during the past 15 years following Vistelius (1949) and others (Krumbein, 1967; Read, 1969). The Markov process is considered to be a natural process that is random in its occurrence in which probability of the process being in a given state at a particular time may be deduced from knowledge of the immediately preceding state. Markov chain in its general form has a very short "memory" extending only for a single step. Such a chain can be termed as first order Markov chain (Vistelius, 1949; Griffiths, 1966). Markov chain may have a longer memory and has a higher order chain if probability associated with each transition depends on events earlier than the immediately preceding events. Markov chain analysis has been considered to be a useful tool in the interpretation of vertical transition of sedimentary sequence (Griffiths, 1966; Krumbein, 1967; Read, 1969; Gingerich, 1969; Miall, 1973; Casshyap, 1975). This same statistics has recently been applied to study cyclicity in Lower Gondwana rocks of India (Tewari, 1977, 1980; Khan, 1978; Aslam, 1980; Kumar, 1981; Casshyap and Khan, 1982).

In the present study first order embedded Markov chain analysis is applied to deduce cyclical order of lithofacies in the Barakar coal measure of Talcher coalfield.

Analytical Method

As a first step to this study, a transition or tally count matrix is structured following the embedded Markov model of Krumbein and Dacey (1969), according to which a given lithology cannot pass into same lithology. This method has been used by most workers referred to above. Transition count matrix so structured is used for computing various other matrices including :

1. Independent Trial probability matrix (e_{ij})
2. Transition probability matrix (p_{ij})
3. Difference matrix (d_{ij})

Analytical methods of Markov chain analysis have been summarised in several recent text books of statistics as applied to geology (Harbaugh and Bonham-Carter, 1970; Davis, 1973). Elements in transition count matrix are referred to as the symbol f_{ij} where i = row number, j = column number. Transitions have only been recorded where lithofaices show an abrupt change in character, regardless of thickness. In this method zero values appear in the principal diagonal of matrix.

Independent Trial matrix (e_{ij}) is computed by the following relationship :

$$e_{ij} = \frac{c_j}{N - S_i}$$

Where N = total number of entries, c_j and c_i represents total number of reading in jth column and in the ith row. It represents the probability of the given transitions occurring randomly.

Transition probability matrix is represented by p_{ij}, which gives the actual probabilities of the given transitions occurring in the given succession and is calculated using the formula as follows :

$$p_{ij} = \frac{f_{ij}}{e_i}$$

Where p_{ij} represents the probability of the ith state being succeeded by jth state. f_{ij} represents values in the transition count matrix. Sum of the p_{ij} matrix values may reflect the presence of Markovian property.

Difference Matrix represents the difference between observed (p_{ij}) and expected (e_{ij}) probabilities (Gingerich, 1969). This matrix has both positive (+ve) and negative (-ve) values and sum of each row always should be zero. The positive (+ve) values in this matrix indicate the upward transition, which have a higher probability of occurrence in the observed data than would be expected whereas lower or negative (-ve) values do not show significant transition statistically. Lower positive (+ve) values in the order of 0.20 or less are not considered statistically significant in structuing upward transition path (Read, 1969). Difference matrix is not quite effective where tally counts for a particular lithologic state in a sequence is too small.

Test of Significance :

Chi-square statistics is usually applied to test the randomness of a distribution. It is a measure of degree of discrepancy present between the observed and expected frequencies. Chi-square statistics after Billingsley (1961) was used to test the Markov property. It gives the probability that the observed transition count matrix (f_{ij}) is the result of random process operating within the observed frequencies of rock types. It can be computed as :

$$\chi_v^2 = \sum_{ij}^{n} (f_{ij} - f_i \cdot e_{ij})^2 / f_i \cdot e_{ij}$$

Where f_{ij} = transition count matrix

f_i = frequency distribution of rock type

e_{ij} = independent trial matrix

v = degree of freedom to be calculated by total number of positive entries in e_{ij} matrix minus the rank of e_{ij}.

VERTICAL TRANSITION OF LITHOLOGICAL STATES IN BARAKAR STRATA

The study reported here is based on 14 borehole logs referred to earlier and transition count data for the given borehole logs were structured and analysed, following the method stated above. This study aims at determining preferred upward transition path of the constituent lithologic states comprising the Barakar strata. The lithologic states in the borehole logs were defined on the basis that they are recorded in the borehole logs, should each be readily recognised in adjoining outcrop sections and have potential geological significance. Transitional lithofacies recorded in borehole logs such as carbonaceous shale and sandy shale are here combined together and counted as shale, whereas, shaly coal is lumped with coal; and likewise, alternate sandstone and shale are arbitrarily lumped half with sandstone and half with shale to form a dominant three lithologic states model to test the Markovian property as follows :

A = sandstone, B = shale, C = coal.

To deduce the realiability of vertical lithologic transitionsof the successions obtained in borehole logs, the area was divided into three sectors, namely (1) Eastern (2) Western (3) Central sectors (Fig. 2) Transition count matrix was structured separately for the three sectors and collectively for the entire area by pooling tally counts of the three aforesaid sectors.

A total of 310 transition counts was obtained from 14 borehole logs for total area, combining 116, 114, 80 count for Eastern, Western and Central sectors respectively. Markov analysis of the three sectors is recorded separately in Tables 2, 3, 4, and for total area in Table 5. Chi-square values as applied to computed values of matrices at 3-degree of freedom are 19.81 for total area (Table 6) and 18.33, 18.29, Table - 2 : Markov Matrices of Lithologic Type in Eastern Sector of Talcher Colliery.

Transition Count Matrix (f_{ij})

	A	B	C	Total
A	0	3	22	25
B	4	0	48	52
C	22	47		69
	26	50	70	146

Independent Trial Matrix (e_{ij})

A	A	B	C
A	0	.42	.58
B	.26	0	.74
C	.33	.67	0

Transition Probability Matrix (p_{ij})

	A	B	C
A	0	.12	.88
B	.08	0	.92
C	.32	.68	0

Difference Matrix (d_{ij})

	A	B	C
A	0	-.3	+.3
B	-.18	0	+.18
C	-.01	+.01	0

A = Sandstone, B = Shale, C = Coal

Table - 3 : Markov Matrices of Lithologic Types in Western Sector of Talcher Colliery.

Transition Count Matrix (f_{ij})

	A	B	C	Total
A	0	2	14	16
B	4	0	28	32
C	12	31	0	53
	16	33	42	101

Independent Trial Matrix (e_{ij})

	A	B	C
A	0	.49	.51
B	.33	0	.67
C	.33	.67	0

Transition Probability Matrix (p_{ij})

	A	B	C
A	0	-.12	+.88
B	-.12	0	+.88
C	.28	.72	0

Difference Matrix (d_{ij})

	A	B	C
A	-.0	-.37	+.37
B	-.21	0	+.21
C	-.05	+.05	0

A = Sandstone, B = Shale, C = Coal

Table - 4 : Markov Matrices of Lithologic Type in Central Sector of Talcher Colliery.

Transition Count Matrix (f_{ij})

	A	B	C	Total
A	0	4	6	10
B	3	0	30	33
C	8	29	0	37
	11	33	36	80

Independent Trial Matrix (e_{ij})

	A	B	C
A	0	.47	.53
B	.22	0	.78
C	.24	.76	0

Transition Probability Matrix (p_{ij})

A	A	B	C
A	0	.4	.6
B	.10	0	.9
C	.21	.79	0

Difference Matrix (d_{ij})

	A	B	C
A	0	-.07	+.07
B	-.12	0	+.12
C	-.03	+.03	0

A = Sandstone, B = Shale, C = Coal.

Table - 5 : Markov Matrices of Lithologic type for Total Area.

Transition Count Matrix (f_{ij})

	A	B	C	Total
A	0	9	42	51
B	11	0	106	117
C	42	100	0	142
	53	109	148	310

Independent Trial Matrix (e_{ij})

	A	B	C
A	0	.45	.55
B	.26	0	.74
C	.3	.7	0

Transition Probability Matrix (p_{ij})

	A	B	C
A	0	.18	.82
B	.09	0	.91
C	.29	.71	0

Difference Matrix (d_{ij})

	A	B	C
A	0	-.27	+.27
B	-.17	0	+.17
C	-.01	+.01	0

A = Sandstone, B = Shale, C = Coal

Table - 6 : Chi-square statistics to test the Markovian property in different sectors and in total area.

Test of Equation	n^2	Degree of Freedom (v)	Limiting value
1. Eastern Sector	18.33	3	12.8
2. Western Sector	18.299	3	12.8
3. Central Sector	3.516	3	12.8
4. Total Area	19.81	3	12.8

3.51 for eastern (Table 6) western (Table 6) and central (Table 6) sectors. These values, by and large are higher than the tabulated values of chi-square at 3-degree of freedom and at 99.5% confidence level (12.8); the exception being the Central sector which yields a lower value (3.51) of chi-square. Thus, presence of Markov property is indicated in the eastern and western sectors representing the presence of cyclical order in Barakar strata; in the central sector the sequence lacks Markovian or cyclical property because of lack of data, perhaps.

Selection of basal unit for the preferred upward transition is based on the maximum transition probability (p_{ij}) value and that of positive value of difference matrix. These values are greater for sandstone in this study (Tables 2, 3, 4, 5). Sandstone is therefore considered as a basal unit for the vertical transition sequence as deduced in this study.

PREFERRED UPWARD SEQUENCE AT SECTOR LEVEL

The preferred upward transition of lithologic states as brought out from corresponding transition probability values of p_{ij} matrix for the two sectors, as shown in Markov diagrams in Fig.14, is as follows :

Eastern Sector : sandstone ⟶ coal ⟶ shale ⟶ coal ⟶ sandstone

Western Sector : sandstone ⟶ coal ⟶ shale ⟶ coal ⟶ sandstone

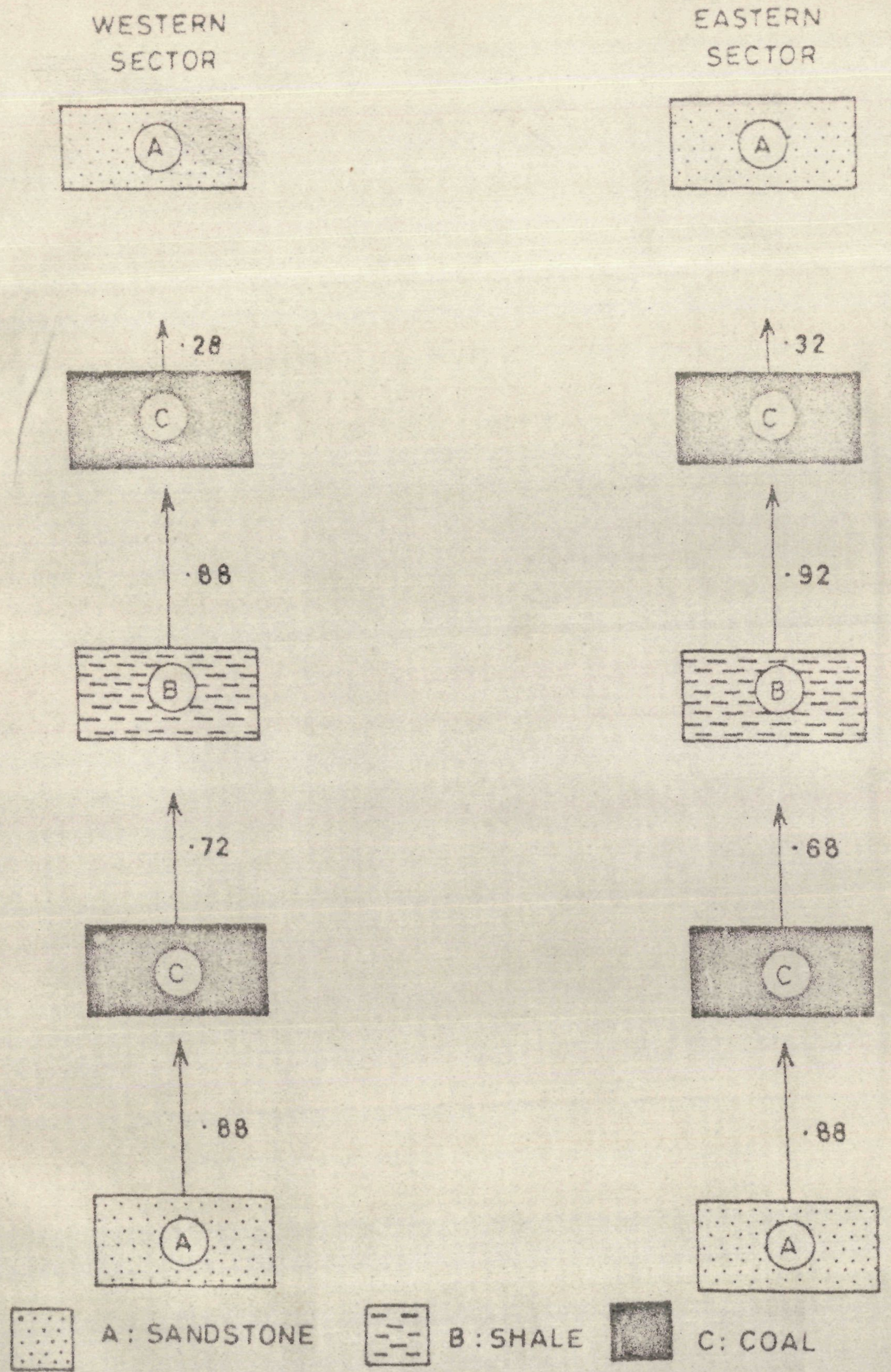


Fig. 14 : Markov diagrams showing preferred upward transitions of lithologic states in the Barakar strata based on transition probability matrix (p_{ij}) in eastern (a) and wester (b) sectors.

Evidently the preferred upward transition of lithologic states calls for a symmetrical (Weller, 1960) fining upward cycle in both the sectors.

Positive (+ve) values of difference matrix (d_{ij}) for the two sectors, likewise, reveal the same type of cyclical order (Fig. 15) i.e. from sandstone through coal to shale and from shale to coal.

PREFERRED UPWARD SEQUENCE IN TOTAL AREA

The Markov model for total area shows similar results as those derived at sector levels. The transition probability values show a symmetrical fining upward cycle (Fig. 16A) as : sandstone $\longrightarrow$ coal $\longrightarrow$ shale $\longrightarrow$ coal $\longrightarrow$ sandstone. Identical cyclical order is brought out (Fig. 16B) from the difference matrix (d_{ij}).

COMPARISION OF BARAKAR CYCLES IN GONDWANA COALFIELDS

Cyclical sequence of Barakar strata has recently been evaluated in several Gondwana coalfields of Damodar Valley and Singrauli basin. The cyclical sequence so deduced using first order Markov chain analysis on subsurface data are schematically summarised in Fig. 17 for Saharjuri (Tewari, 1980), East Bokaro (Casshyap and Khan, 1982), Jharia (Kumar, 1981), Singrauli (Casshyap, 1979; Aslam, 1980), and are compared with that of Barakar strata of Talcher coalfield (this study).

The Barakar strata in all the coalfields exhibit more or less symmetrical fining-upward cycles. But there are differences in

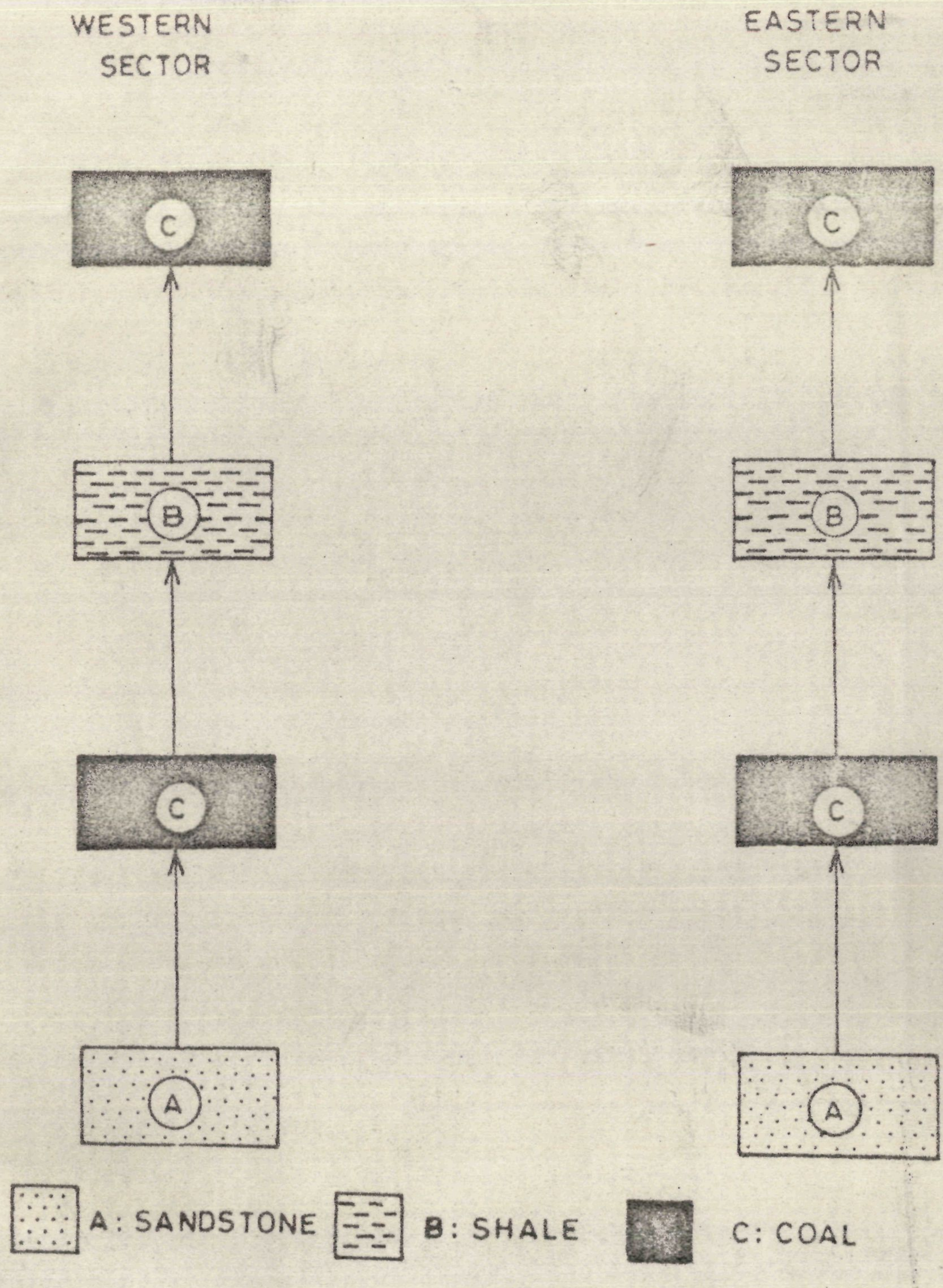


Fig. 15 : Markov diagrams showing preferred upward transitions of lithologic states in the Barakar strata based on difference matrix (d_{ij}) in eastern (a) and western (b) sectors.

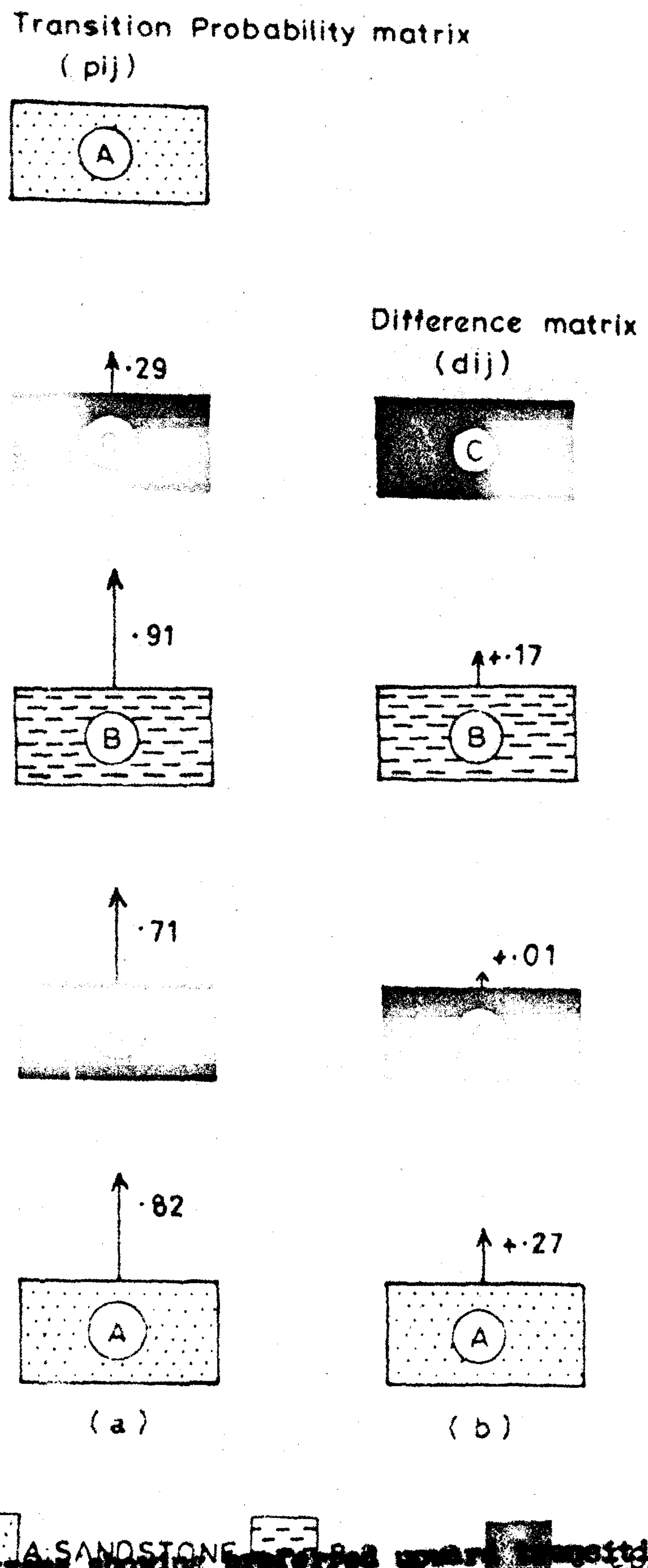


Fig. 16 : Markov diagrams showing preferred upward transitions of lithologic states in the Barakar strata based on transition probability (p_{ij}) (a) and difference (b) matrices, deduced from pooled data from total area.

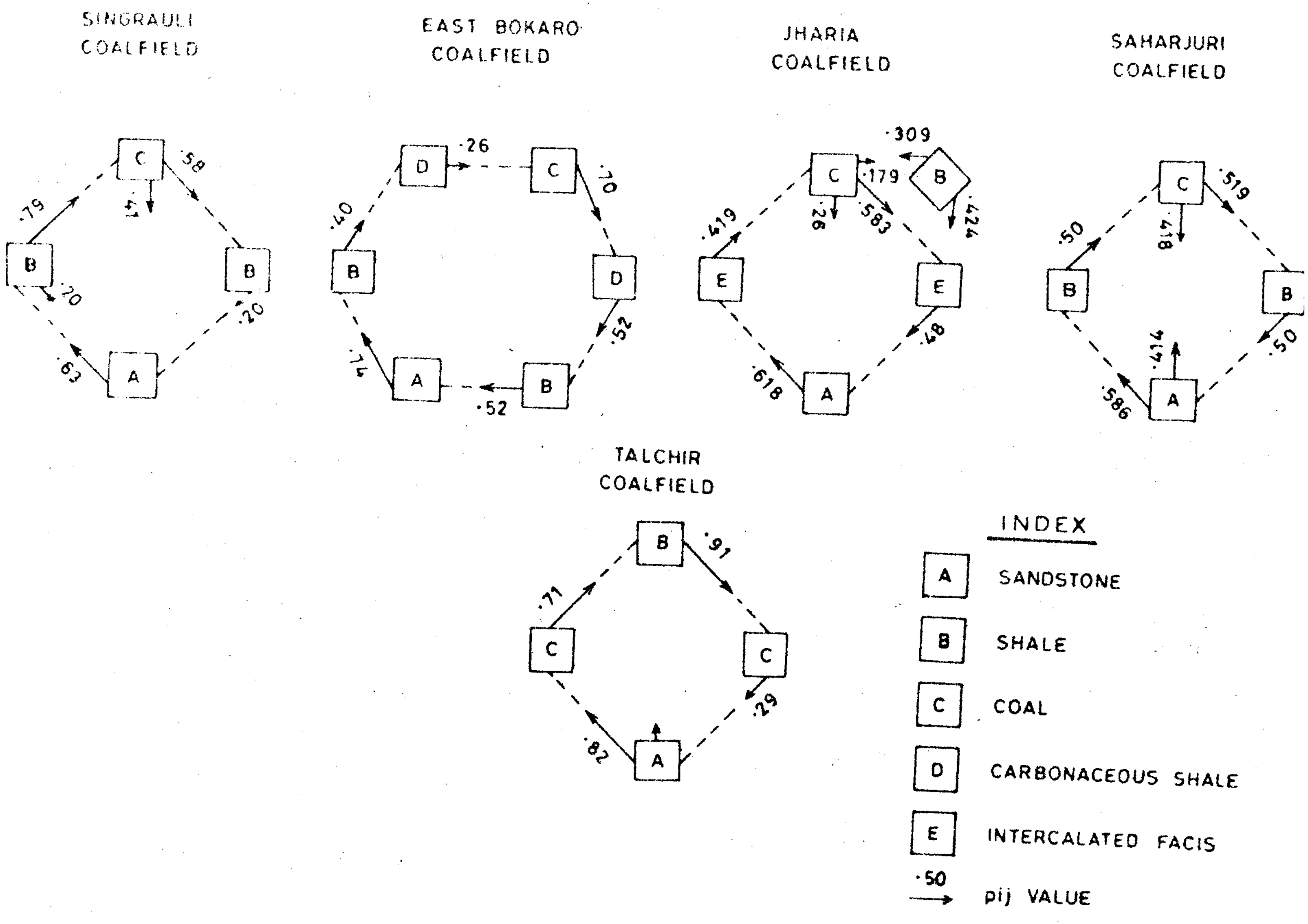


Fig. 17 : Diagram showing cyclical sequences in the Barakar strata of the given area, and other Gondwana basins. The symmetrical nature of Barakar cycles in the given area and other basins is noteworthy.

transitions between different lithologies in different coalfields. The main difference lies in the memory of coal vis-a-vis other lithologies. Thus, coal shows greater memory for shale in the Saharjuri and Singrauli coalfields, carbonaceous shale in East Bokaro, and interbedded facies in Jharia coalfield, and is, in turn, followed above by the preceding lithologies. As against this, coal exhibits a greater memory for sandstone and is turn overlain commonly by sandstone almost in all the borehole logs of Talcher colliery.

This difference in cyclical order in the Barakar strata between Talcher coalfield and other Gondwana coalfields situated further north is indeed of genetic significance, and may have to do with differences in channel morphology of the depositing streams in respective basins, as explained later.

CHAPTER - IV

GEOLOGICAL INTERPRETATION

Combined results from subsurface lithofacies analysis and Markov chain analysis of Barakar strata of Talcher coalfield provide evidence for reconstructing basin framework, depositional environments, tectonic framework, and for evaluating coal potentiality.

The subsurface analysis indicates asymmetrical subsidence of the depositional basin, greater towards southeast and northwest than the central part. Closer spacing of form lines suggest that the subsiding basin may have steeper profile in the centre and gentle farther away toward south and north. Structural stike of Gondwana rocks is more or less parallel to the strike of isopach formlines. The facies formlines also show a parallel relationship with isopach formlines. This relationship indicates that basin subsidence was contemporaneous with the deposition of lithofacies.

Subsurface analysis of individual lithofacies provides an idea about the basin framework and depositional environment. Sandstone bodies show elongate roughly ENE-WSW (Fig. 7). Areas of greater thickness and percentage of sandstone more or less coincide with the trend of subsiding basin and may correspond with width of the main streams channels at the time of deposition, channel length being across the width, from SE to NW, as stated earlier. Geometry of sandstone bodies as shown in panel diagram (Fig. 4) and their thickness distribution (Fig. 5) show two types of bodies : one, continuous and sheet like with lenses of shale and/or coal; the other, discontinuous lensoid and channel shaped enclosed in shale or coal. The areas showing lesser sandstone, implying less accumulation of sand, for instance those in the central part, correspond to interchannel environment and/or overbank. These areas appropriately contain greater amount of fine clastics as shown by shale percentages (Fig. 10) and sand-shale ratio map (Fig. 11). The coal isolith map (Fig. 12) reveals that distribution of coal is not controlled by either of the two lithologies, in that it occurs in greater amount both in the southern part coinciding with greater amount of sandstone and in northern part with greater amount of shale. The relationship indicates that coal forming swamps as and when developed across a large part of the flood plain, previously occupied by stream channels as also extended overbank or through interchannel areas. Recurrence of sandstone, shale and coal in vertical columns indicates that these were deposited by repeated lateral shifting of channels and subenvironments. The presence of thick coal seams on top of sandstone in particular and fine clastics, locally (Fig. 4) indicates that swampy conditions developed and lasted long on different lithologies. However, the coal forming conditions were interrupted, locally, due to periodic supply of sand or clay through crevass-splays, as is evident from the occurrence of thin lenses of sandstone and shale in coal seams. Greater subsidence towards south and northwest may account for favourable conditions for development of swamps and accumulation of vegetal debris as indicated by greater amount (48.26%) of coal in these peripheral areas (Fig. 12).

The Markov statistics of Barakar strata underlying the study area shows symmetrical cycles in small areas of sector level and in the total area, as follows :

Sandstone $\longrightarrow$ coal $\longrightarrow$ shale $\longrightarrow$ coal $\longrightarrow$ sandstone

The basal unit which is commonly gritty, coarse grained, cross-bedded sandstone may be interpreted as channel bars or braid bars. Sandstone shows upward transition intocoal with strong probability values of about 80% (p_{ij} 0.82) which represents greater probability of occurrence of swampy lacustrine conditions favourable for coal formation. Alternation of shale and sandstone as recorded in some borehole logs may imply re-currence of lean periods of rivers during which sandy bars were covered by fine clastics, a common phenomenon of braided rivers during lean (winter) periods. Alternatively, the inter-bedded relationship may imply overbank subenvironment. Likewise, alternation of coal and shale as recorded by greater p_{ij} values (0.71, 0.91) may be due to back-and-forth migration of muddy environment on coal forming swamps.

The combined evidences from subsurface and Markov chain analysis suggest that a gradual lateral shifting of main channel and associated subenvironements in alluvial plain may account for the origin of symmetrical fining-upward cycles in Barakar strata, as also suggested by early workers (Allen, 1964; Casshyap, 1970; Tewari, 1977; Khan, 1978).

It is suggested that the coal forming environment of Talcher basin was associated with braided system of streams which deposited multistorey and multilateral sand bodies in the subsiding alluvial plain. The Talcher basin in this respect differs from other Gondwana basins like Saharjuri, East Bokaro, Jharia, and Singrauli situated distally towards north in the upcurrent direction, where the depositional basins and coal formation were associated largely with sinuous and meandering system of streams (Casshyap, 1977).

CHAPTER - V

SUMMARY AND CONCLUSION

The Gondwana rocks in Talcher coalfield covering an area of about 1800 sq km are bounded on all sides by unclassified Archean granites and gneisses. Total thickness of Gondwana rocks including lower and upper Gondwana is of about 1550 meter. The study area of the Talcher colliery forms the eastern parts of Talcher coalfield situated in the district of Dhankanal of Orissa. The Talcher colliery is located on the Barakar Formation.

The study is based on data derived from 14 borehole logs which were appropriately analysed for subsurface investigation. Subsurface analysis of lithic-fill was carried out to work out the basin framework, vertical transition of lithologic states, and depositional environment, as follows :

A panel diagram was drawn between two Marker horizons, namely upper Marker Horizon Coal Seam and lower Bottom Coal Seam. This diagram demonstrates three dimensional distribution of lithofacies. Sandstone occurs generally as sheet like continuous bodies; some are laterally discontinuous having a lensoid and channel shape geometry. Interbedded coal seams, likewise, occur as continuous and discontinous bodies.

Isopach map demonstrates asymmetrical type of subsidence in the elongate basin. The maximum subsidence occurs towards north and south at peripheral side and minimum in central part. Slope of profile is steeper in the central part and gentler farther away towards north and south. The strike of form lines coincides more or less with the structural strike and with facies strike.

Sandstone isolith map shows maximum development of sandstone in the eastern and southeastern part and minimum in the northern and northcentral part. A prominent sandstone body called here the Middle Sandstone shows more or less the same pattern of thickness as recorded for total sandstone. Percentage maps show that development of shale is maximum in the areas of minimum development of sandstone. This is also indicated by sand-shale ratio map.

Isolith map of coal shows maximum development of coal in the outer peripheral part of the elongate basin, as against the central part. The Top Coal Seam shows greater thickness in the outer eastern, northwestern, and in the central part and smaller towards western part. The zig-zag shape of Top Coal Seam in isolith map may indicate original shape and configuration of coal-forming marsh in the Barakar flood plain.

First Order embedded Markov chain analysis is applied to deduce vertical order of transition of lithofacies in the Barakar coal measures at different sectors and for total area. A Chi-square test is applied to confirm the presence of Markov property. The Chi-square test confirms the presence of Markov property in two of the three sectors and in the total area. The preferred upward transition of lithologic states as brought out from corresponding transition probability values of p_{ij} and difference matrix values (d_{ij}) for different sectors and for total area, shows symmetrical fining upward cycle represented by : sandstone $\rightarrow$ shale $\rightarrow$ coal $\rightarrow$ shale $\rightarrow$ sandstone.

The combined evidence from subsurface and Markov statistics suggest that lateral shifting of river channels and associated subenvironments of alluvial plain may account for the origin of symmetrical fining-upward cycles in the given Barakar strata.

The reported cyclical sequences of the Barakar of Damodar- and Son-Valley coalfields were compared with that of the Talcher coalfield. The Barakar strata exhibit more or less symmetrical fining-upward cycles in all coalfields. There are though difference in transition between different lithologies in different coalfields. The differences in lithological transition may have developed due to local differences in subenvironments.

It is suggested that the coal forming environment of Talcher basin was associated largely with braided streams, so that the resultant sediments are mainly arenaceous and coal seams thin and regionally impersistent. In this respect this basin differs from other Gondwana basins located distally in upcurrent direction, towards north, where sediment deposition and coal formation were associated largely with sinuous and meandering system of streams. Indeed, the resultant sediments in these basins are rich in fine clastics and interbedded coal seams, not uncommonly, are thick and laterally persistent.

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